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(54) **MODULAR ELECTRONIC DISPLAYS**

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G09G 3/34	(2006.01)
H04N 9/12	(2006.01)
H04N 9/31	(2006.01)

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CPC ***G09G 3/20*** (2013.01); ***G06F 3/1446*** (2013.01); ***G09G 3/3426*** (2013.01); ***H04N 9/12*** (2013.01); ***H04N 9/3155*** (2013.01); ***H04N 9/3158*** (2013.01); ***H04N 9/3164*** (2013.01); ***H04N 9/3194*** (2013.01); ***H04N 9/3197*** (2013.01); *G09G 2300/026* (2013.01); *G09G 2320/0646* (2013.01); *G09G 2320/0693* (2013.01); *G09G 2330/08* (2013.01); *G09G 2360/145* (2013.01); *G09G 2360/16* (2013.01)

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None
See application file for complete search history.

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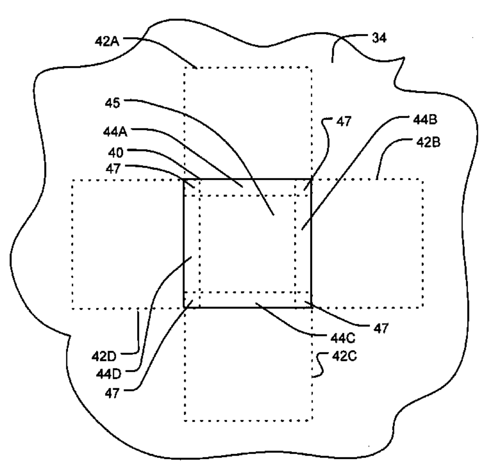
Primary Examiner — Antonio Xavier

(57) **ABSTRACT**

Modular displays are made up of arrays of modules that include light sources and light modulators. The modules may include control circuits that perform some image processing functions. The modules may illuminate a screen directly or may include optical systems that project light onto a screen.

42 Claims, 6 Drawing Sheets



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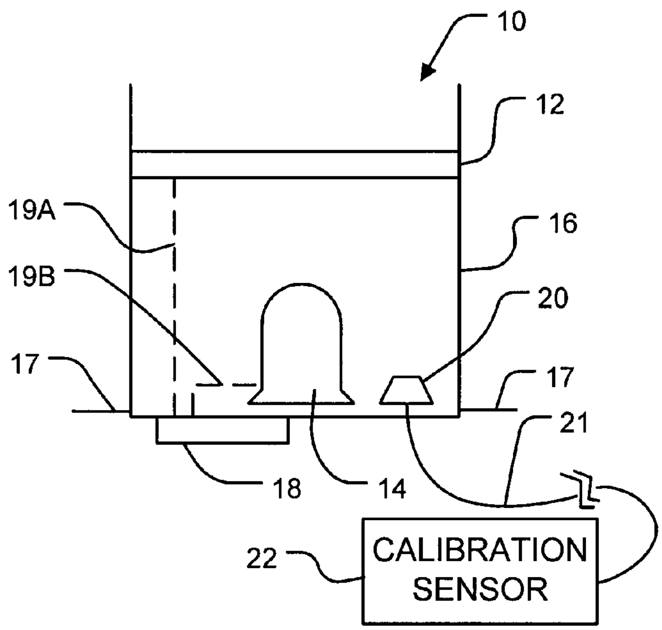

FIGURE 1

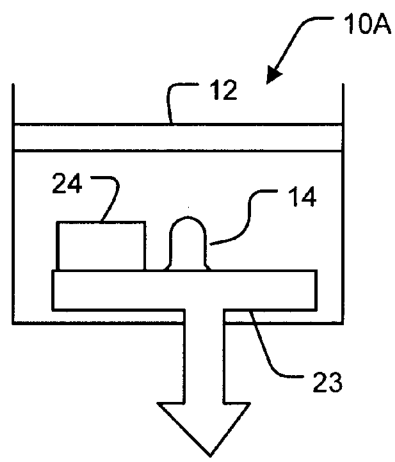

FIGURE 1A

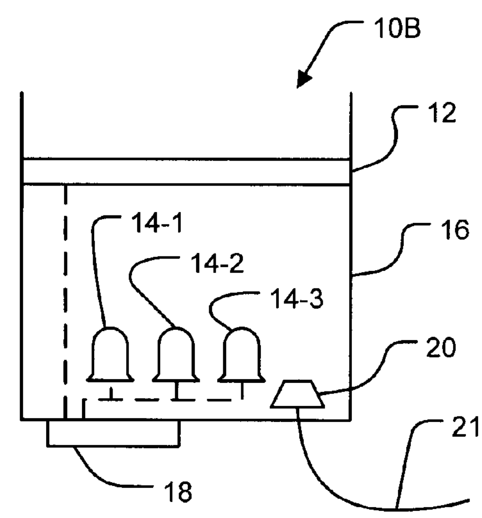

FIGURE 1B

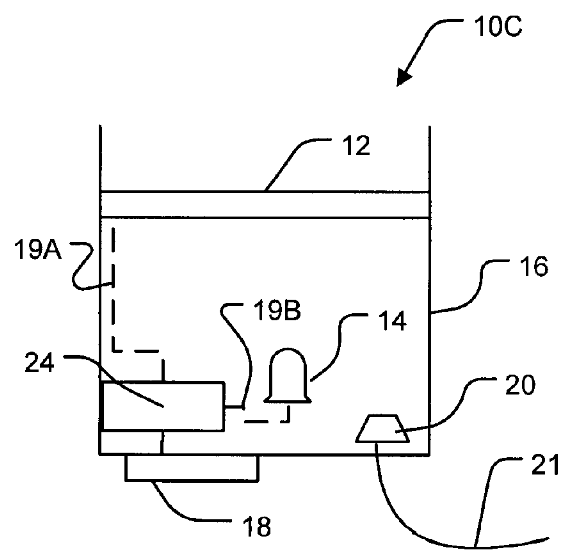

FIGURE 1C

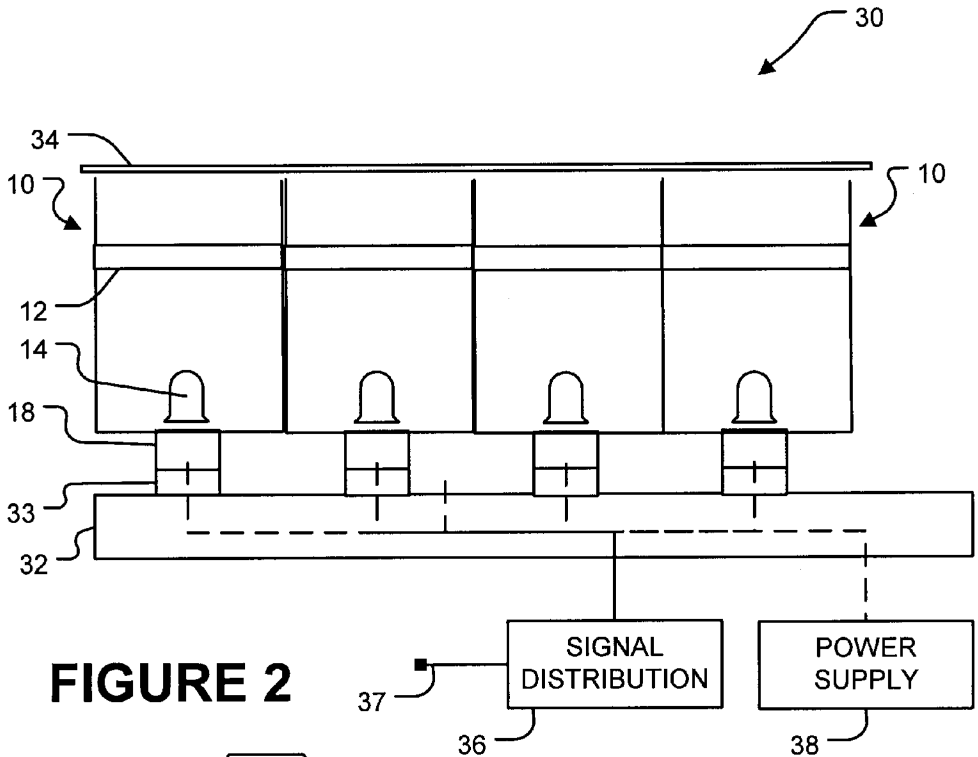

FIGURE 2

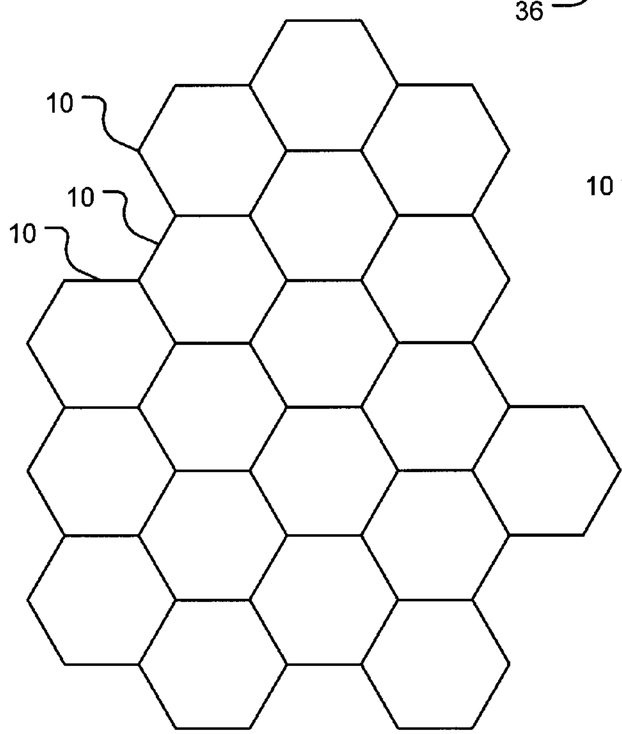

FIGURE 2A

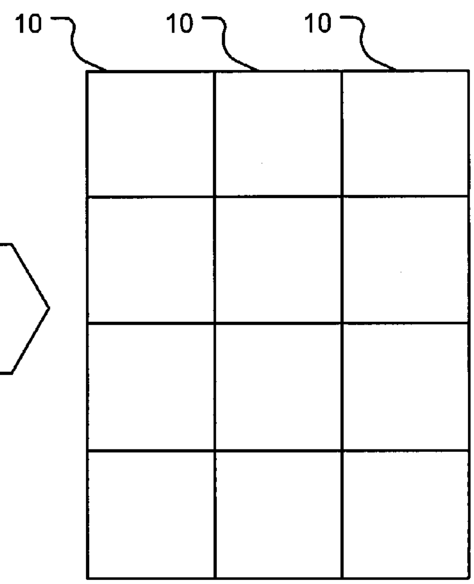

FIGURE 2B

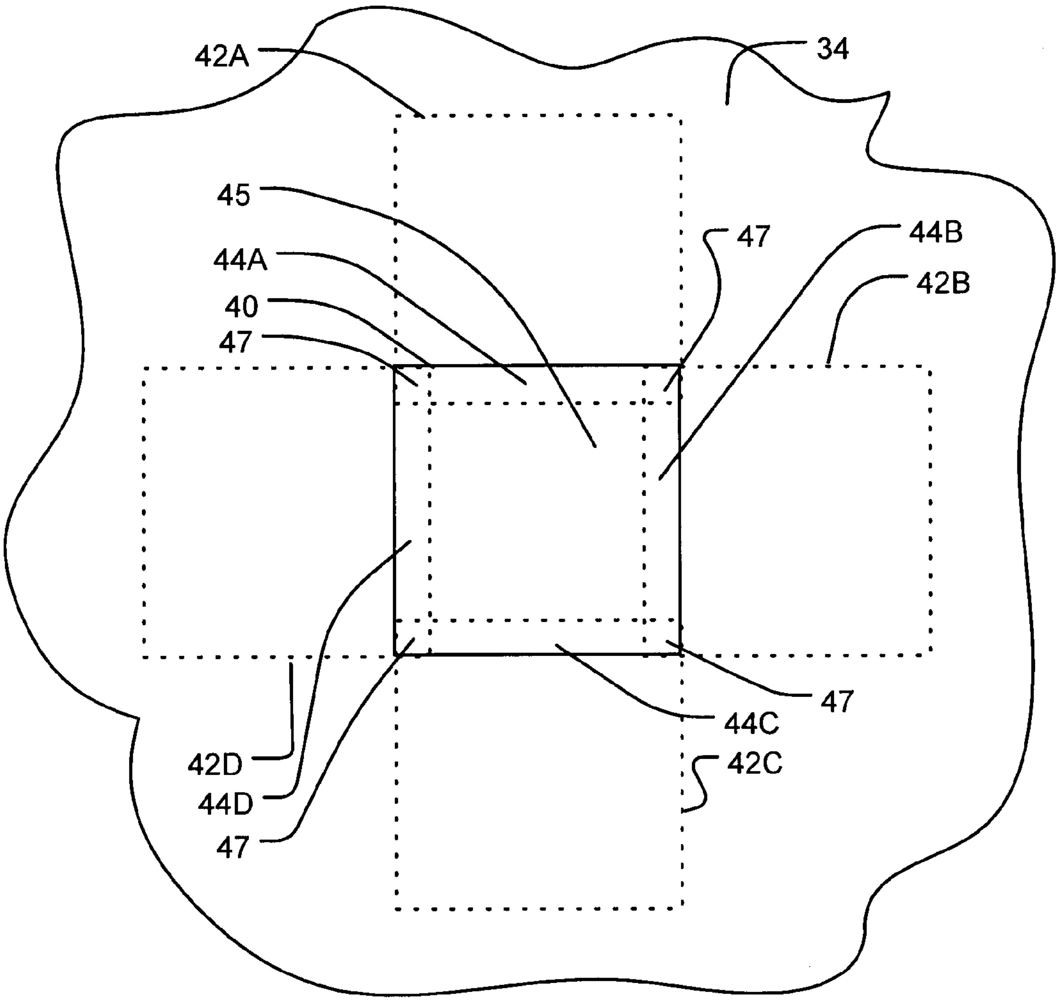

FIGURE 3

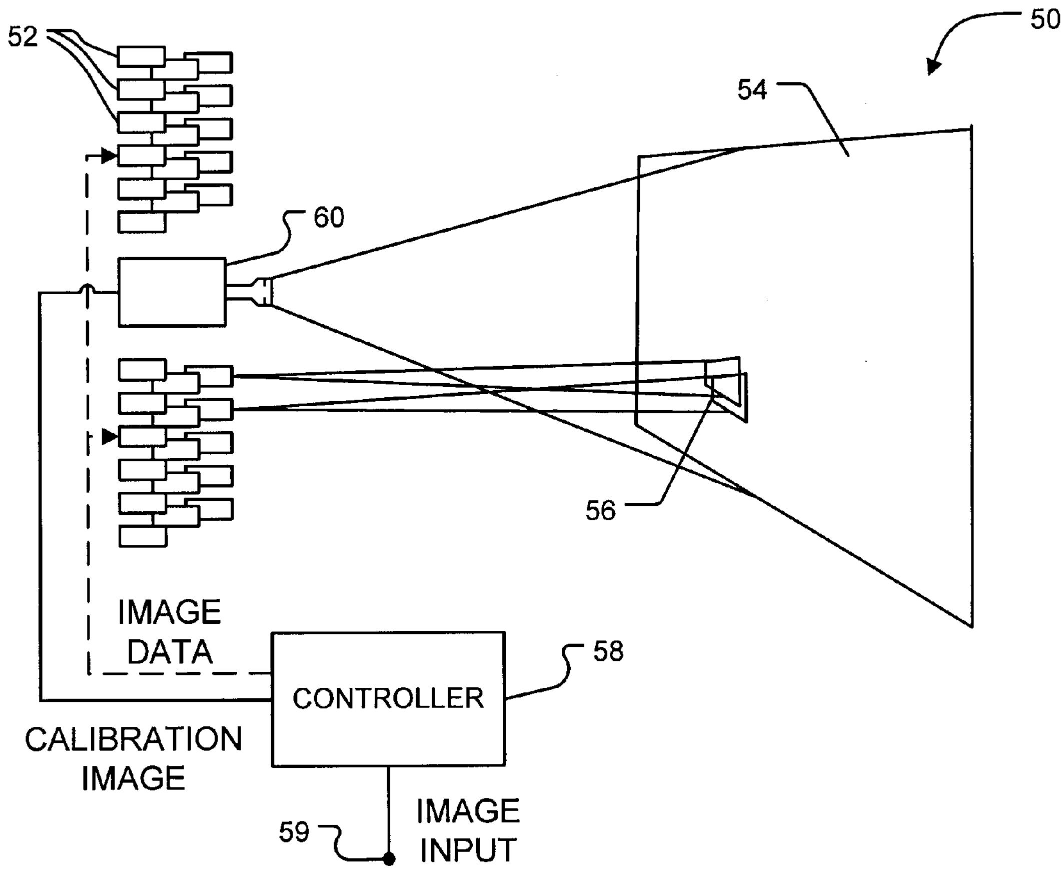

FIGURE 4

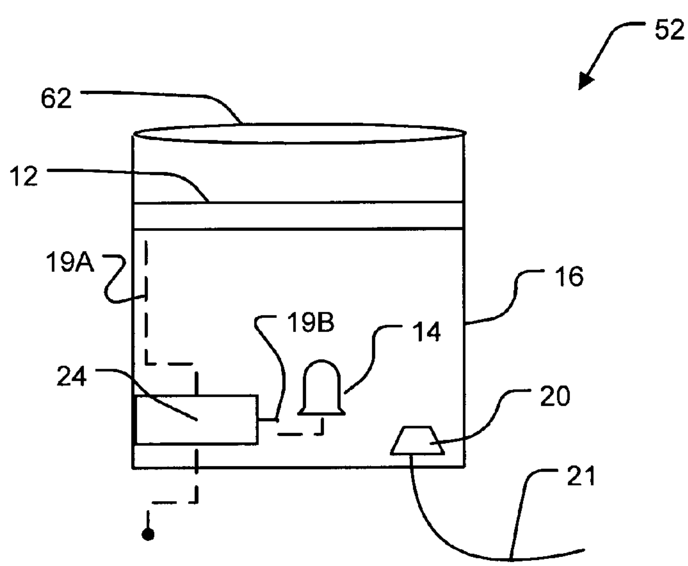

FIGURE 5

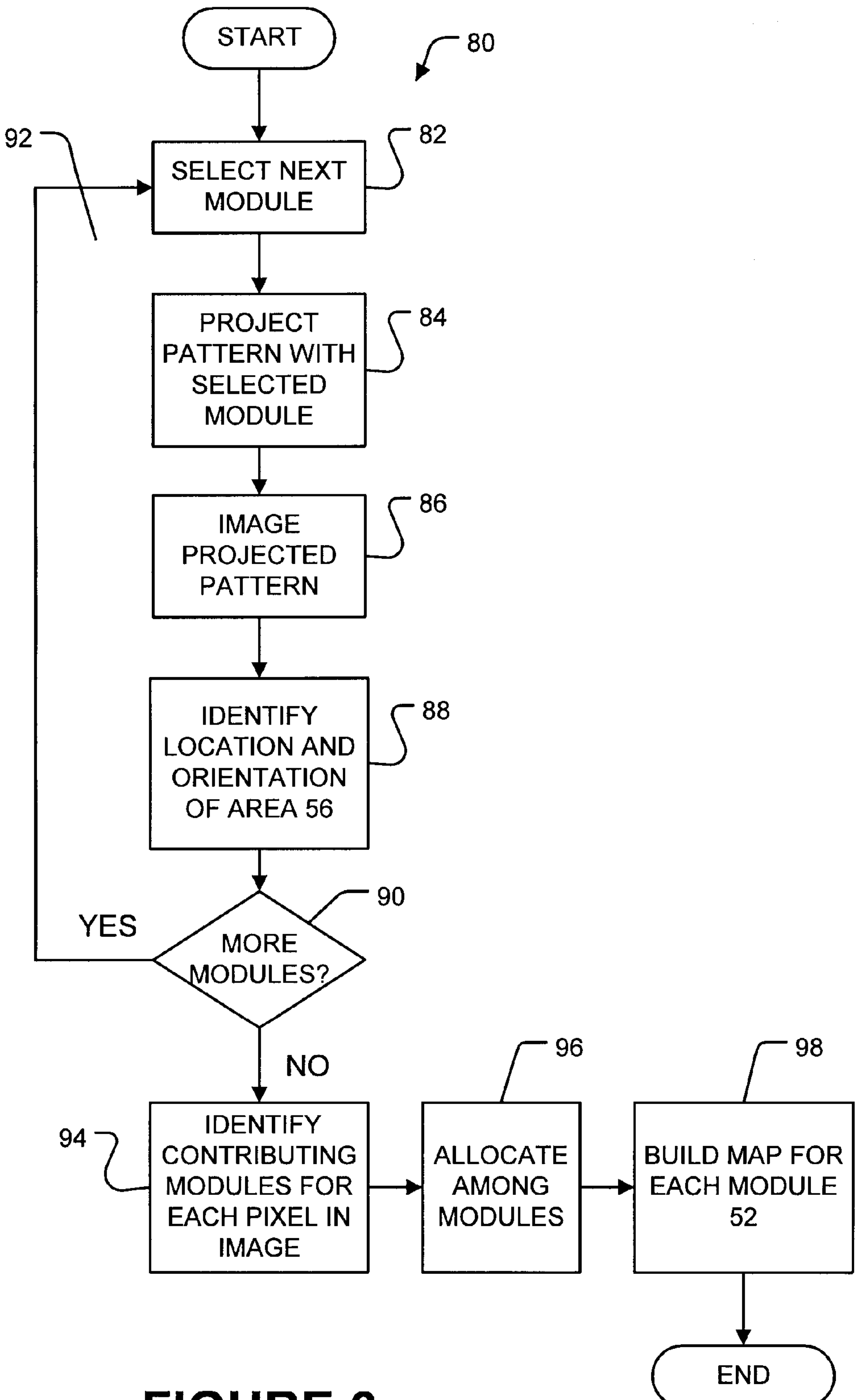
START
80
92
SELECT NEXT MODULE
82
PROJECT PATTERN WITH SELECTED MODULE
84
IMAGE PROJECTED PATTERN
86
IDENTIFY LOCATION AND ORIENTATION OF AREA 56
88
YES
MORE MODULES?
90
NO
96
98
94
IDENTIFY CONTRIBUTING MODULES FOR EACH PIXEL IN IMAGE
ALLOCATE AMONG MODULES
BUILD MAP FOR EACH MODULE 52
END

FIGURE 6

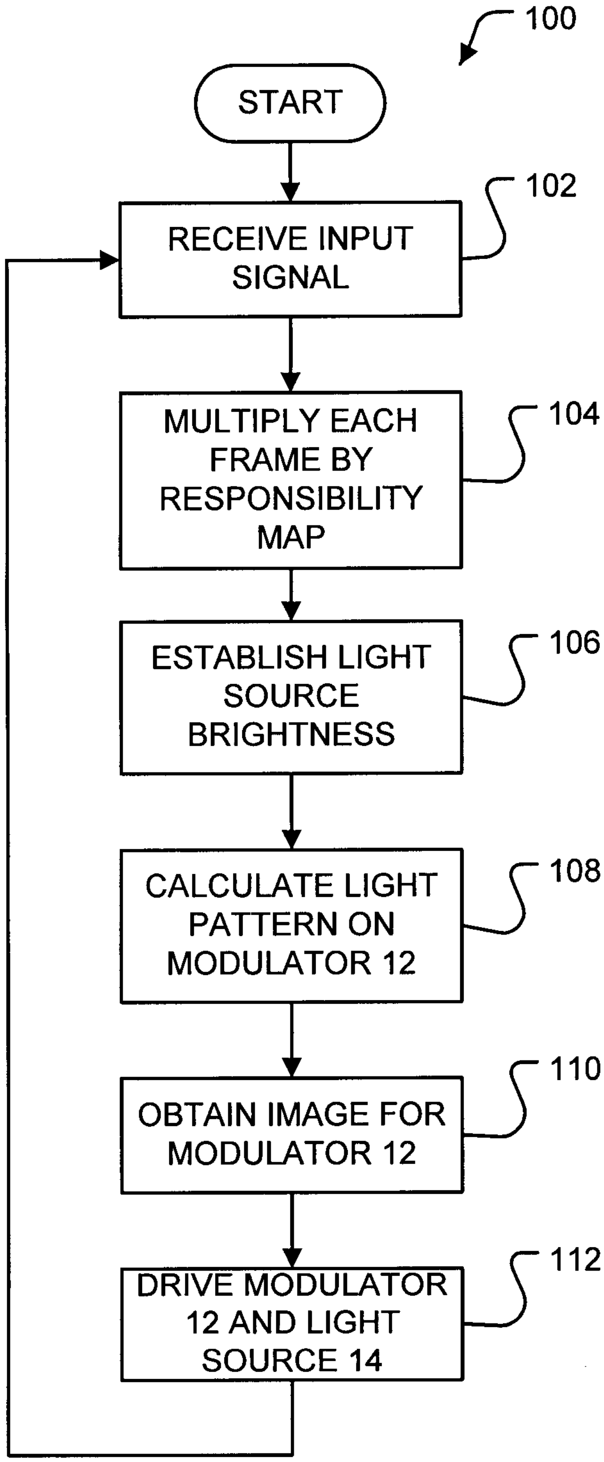
100
START
RECEIVE INPUT SIGNAL
102
MULTIPLY EACH FRAME BY RESPONSIBILITY MAP
104
ESTABLISH LIGHT SOURCE BRIGHTNESS
106
CALCULATE LIGHT PATTERN ON MODULATOR 12
108
OBTAIN IMAGE FOR MODULATOR 12
110
DRIVE MODULATOR 12 AND LIGHT SOURCE 14
112

FIGURE 7

MODULAR ELECTRONIC DISPLAYS

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority from U.S. patent application Ser. No. 60/748,125 filed on 6 Dec. 2005 and entitled MODULAR ELECTRONIC DISPLAYS, which is hereby incorporated herein by reference. For purposes of the United States, this application claims the benefit of U.S. patent application Ser. No. 60/748,125 under 35 U.S.C. §119.

TECHNICAL FIELD

The invention relates to displays for computers, cinemas, televisions and the like. Some embodiments of the invention provide projection-type displays. Other embodiments of the invention provide display screens.

BACKGROUND

U.S. Pat. No. 6,891,762 discloses displays in which the light output for each pixel is determined by two signals. In some embodiments, one signal controls the light transmission of a first light modulator and a second signal controls the intensity of the light that is incident on a part of the light modulator that corresponds to the pixel. The second signal may control directly a light source, such as a light emitting diode (LED) that illuminates a portion of the first light modulator, or may control a modulator located between a light source and the first light modulator.

There is a need for electronic displays that are reliable and cost-efficient to manufacture and repair. There is a particular need for such displays that can provide high dynamic ranges. Such needs exist for both projection-type displays and displays that have an integrated screen.

SUMMARY OF THE INVENTION

One aspect of the invention provides displays that comprise a plurality of modules. Each of the modules comprises a light source and a spatial light modulator disposed to modulate light emitted by the light source in response to image data. The display also includes a screen illuminated by the plurality of modules. In some embodiments, each module comprises a processor connected to receive a data signal carrying the image data and to generate a driving signal for the light modulator based on the image data.

Another aspect of the invention provides methods for displaying images on a screen. The methods comprise providing a plurality of modules each comprising an image projector capable of projecting a part of an image onto an area of the screen corresponding to the module. Each of the modules has a corresponding processor. Each of the processors has access to a digital responsibility map corresponding to the corresponding module. The method provides image data defining an image to be projected on the screen to all of the processors, the image covering a plurality of the areas; operates each of the processors to identify using the responsibility map, and to extract from the image data, a subset of the image data corresponding to the area corresponding to the corresponding module, and operates each of the modules to project onto the screen a part of an image defined by the subset of the image data extracted by the corresponding processor.

Another aspect of the invention provides methods for calibrating display systems. The methods comprise operating each of the modules of a display system to display on a screen a pattern indicative of the location of an area of the screen corresponding to the module, acquiring one or more images including each of the displayed patterns, and generating a responsibility map identifying the area of the screen corresponding to each of the modules by processing the one or more images.

Further aspects of the invention and features of specific embodiments of the invention are described below.

BRIEF DESCRIPTION OF THE DRAWINGS

In drawings which illustrate non-limiting embodiments of the invention,

FIG. **1** is a schematic view of a module that can be combined with other modules to provide a display;

FIG. **1**A is a schematic view of a module that includes a thermally-conductive member;

FIG. **1**B is a schematic view of a module that has multiple light sources;

FIG. **1**C is a schematic view of a module that includes a control circuit;

FIG. **2** is a partial schematic view of a display made up of several modules all connected to a backplane;

FIGS. **2**A and **2**B show example alternative ways that modules may fit together to tile the area of a screen;

FIG. **3** shows schematically a portion of a screen in a display having square modules;

FIG. **4** is a schematic view of an image projection system comprising a plurality of modules;

FIG. **5** is a schematic view of a module of a type that may be used in a system like that of FIG. **4**;

FIG. **6** is a flow chart illustrating a method that may be practiced in the initial set up of a system like that of FIG. **4**; and,

FIG. **7** is a playback method that may be performed at each module in a display wherein the modules have on-board processing.

DESCRIPTION

Throughout the following description, specific details are set forth in order to provide a more thorough understanding of the invention. However, the invention may be practiced without these particulars. In other instances, well known elements have not been shown or described in detail to avoid unnecessarily obscuring the invention. Accordingly, the specification and drawings are to be regarded in an illustrative, rather than a restrictive, sense.

This invention relates to displays of the type in which light from an array of light sources is modulated to yield an image on a screen. In preferred embodiments, the intensity of light emitted by each of the light sources is modulated by controlling the light source and the emitted light is modulated by a light modulator after it has been emitted. The light sources and light modulators are disposed in modules that can be individually replaced.

FIG. **1** is a schematic view of a module **10** that can be combined with other modules **10** to provide a display. Module **10** has a modulator **12** illuminated by a light source **14**. Modulator **12** may comprise a transmission-type modulator, such as a liquid crystal display ("LCD") panel or the like. In typical embodiments, each modulator **12** comprises a 2-dimensional array of independently-controllable pixels.

Light source **14** preferably comprises a solid-state light source such as a light-emitting diode ("LED"). However, other types of light sources may be used in the alternative. In preferred embodiments, light sources **14** have variable light outputs.

Module **10** has a housing **16** that supports modulator **12** and light source **14**. Housing **16** may comprise mounting points **17** such as mounting tabs, clips, or the like which allow housing **16** to be mounted to a suitable backplane, as described below. The backplane is typically planar but this is not mandatory.

A connector **18** connects to a corresponding connector. Connector **18** receives signal and power from external sources (not shown in FIG. **1**). Within module **10** a signal **19**A drives modulator **12** and a signal **19**B drives light source **14**. Signals **19**A and **19**B may be received through connector **18** or may be generated in module **10** from other signals received by way of connector **18**.

A light sensor **20** may optionally be provided for calibrating the light output of a module **10**. In some applications this is necessary because of variations in light sources **14** or the components that control light sources **14**. For example, due to manufacturing process variations, different LEDs of the same type may provide different light output even when driven by the same current.

In preferred embodiments, light sensors **20** comprise the ends of optical fibres **21** that carry light to a common sensor **22**. Providing a central sensor **22** for calibration purposes avoids having the accuracy of calibration affected by differences between individual sensors or temperature differences between different modules **10**. In other embodiments, separate light sensors are provided for each module **10**. In some cases, the outputs of light sources **14** is sufficiently predictable that it is not necessary to provide a light sensor **20**.

FIG. **2** is a partial schematic view of a display **30** made up of several modules **10** all connected to a backplane **32**. Backplane **32** comprises connectors **33** that mate with connectors **18** of modules **10**. Modules **10** may be attached to backplane **32** by the interconnection of connectors **18** and **33** and/or by any suitable fastening mechanism. For example, screws or other fasteners may be provided to hold modules **10** in place on backplane **32**.

In some embodiments, backplane **32** is modular. For example, backplane **32** may comprise tiles or strips that each support a plurality of modules **10**. A display of a desired size and configuration can be made by assembling together such tiles or strips. In some embodiments, backplane **32** comprises a plurality of modular strips that each provide support for one or more columns or one or more rows of modules **10**. The modular strips can be assembled together in a substantially parallel arrangement to provide a display of a desired size.

A screen **34** is illuminated by modules **10**. Each module **10** illuminates a corresponding area of screen **34**. The areas of screen **34** illuminated by adjacent modules **10** preferably overlap at least slightly. Screen **34** may be patterned to provide a Fresnel lens corresponding to each module **10**. Screen **34** preferably has light-diffusing properties so that light is scattered toward the location of a viewer. In the illustrated embodiment, light from multiple modules **10** passes through a single screen **34**. In alternative embodiments, screen **34** is modular (e.g. each module **34** may carry a part of screen **34**). Screen **34** may be configured to scatter radiation evenly into an elliptical cone.

A signal distribution system **36** distributes driving signals to each module **10**. The driving signals cause the display to display content provided at an input **37**. Distribution system **36** may provide different driving signals to each module **36** or may provide the same driving signals to each module **10**. If distribution system **36** provides the same driving signals to each module **10** then modules **10** each derive signals **19**A and **19**B from the driving signal. This may be done by extracting parts of the driving signal or by generating new signals based upon the driving signal. A power supply **38** supplies electrical power to modules **10**.

Backplane **32** may provide the additional function of controlling the temperature of modules **10**. This typically involves dissipating heat generated in modules **10**. The heat may be generated, for example, by light source **14** and/or any active electronic devices, logic circuits, control circuits or processors that are in module **10**.

In some embodiments backplane **32** supports a system for managing the temperature of modules **10**. In some such embodiments, modules **10** comprise thermally conductive paths that collect heat generated by devices in the module **10** and carry the heat to backplane **32**. For example, a module **10** may comprise a thermally-conductive post or other member that connects with a heat sink on backplane **32** when the module **10** is attached to backplane **32**. The thermally-conductive member is integrated with connector **18** in some embodiments. Heat generated within the module **10** flows out of module **10** into the heat sink.

FIG. **1**A illustrates a module **10**A that includes a thermally-conductive member **23** that is in thermal contact with light source **14** and control electronics **24**. Thermally conductive member is configured to connect to a heat sink in a backplane **32**.

In other embodiments that include cooling systems, backplane **32** includes channels that carry a flow of cooling air (or other gas) to each module **10**. For example, backplane **32** may support one or more fans that generate a flow of air and a suitable system of manifolds for delivering the air to cool modules **10**.

Modules **10** may vary in various respects. As shown in FIG. **1**B, a module **10**B may have multiple light sources **14**. The illustrated embodiment shows three light sources **14-1**, **14-2**, and **14-3**. These light sources may be of the same or different colors depending upon the application. In some embodiments, modules **10** have red, green and blue light sources (or another set of light sources that spans a color space suitable for the application). In such cases, there may be one, or more than one light source of each color.

FIG. **1**C shows a module **10**C that includes a control circuit **24** that extracts and/or generates signals **19**A and **19**B from a signal provided at connector **18**. Control circuit **24** may include components such as a microprocessor, associated program memory, associated working memory, hard-wired image processing circuits, field programmable gate arrays (FPGAs) and the like. If the module **10**C includes multiple light sources **14** then control circuit **24** may generate separate signal **19**B for each light source **14** or, in some cases, for each color of light source **14**.

As shown, for example, in FIGS. **2**A and **2**B, modules **10** fit together to tile the area of screen **34**. FIG. **2**A shows hexagonal modules **10**. FIG. **2**B shows square modules **10**. Modules **10** may also be of other shapes that can fit together to cover an area. For example, modules **10** may be triangular, rectangular, cruciate, or the like. It is not mandatory (although it is usually convenient) that all modules be identical in cross-sectional shape.

Modules **10** are not necessarily tightly fitted together. In some embodiments, each module **10** is spaced slightly apart from adjacent modules **10**. Modules **10** could also be spaced more widely apart, if desired.

Screen **34** may be flat or curved.

The walls of housing **16** are preferably opaque such that light from each module **10** passes through a well-defined portion of modulator **12**. FIG. **3** shows schematically a portion of a screen **34** in a case where modules **10** are square as shown in FIG. **2**B. An area **40** illuminated by a module **10** (not shown in FIG. **3**) is shown in solid outline. Area **40** overlaps with areas **42**A, **42**B, **42**C, and **42**D illuminated by other modules **10**. For example, along strip **44**A, area **40** overlaps with area **42**A. Along strip **44**B, area **40** overlaps with area **42**B. Along strip **44**C, area **40** overlaps with area **42**C. Along strip **44**D, area **40** overlaps with area **42**D.

In a central area **45** the illumination of screen **34** depends only upon the module **10** corresponding to area **40**. In strips **44**, screen **34** receives light from two modules **10**. In corner areas **47**, screen **34** receives light from four modules **10**.

Display **30** includes a mechanism for controlling adjacent modules **10** to deliver correct levels of illumination within overlapping areas (i.e. within strips **42** and corners **47** in the embodiment of FIG. **3**). The mechanism may include a central processor or processors distributed among modules **10**, for example. The mechanism sets drive levels for each light source **14** and modulator **12** such that the sum of the illumination received from all contributing modules **10** at each point in each overlapping area is an illumination level desired for that point.

Suitable drive levels may be obtained by working backward from the desired illumination levels to obtain values for drive signals to light source(s) **14** and modulators **12** that will result in correct illumination levels within the overlapping areas.

It can be appreciated that the displays can be constructed as described herein in ways that can provide various benefits. For example:

- modules **10** may be built primarily from easily-sourced commodity components. This facilitates providing cost-effective displays.
- displays of almost any size and aspect ratio may be made by combining suitable numbers of modules **10**.
- a display that becomes defective as a result of problems in one or more modules **10** can be repaired by replacing the defective modules **10**.

FIG. **4** shows an image projection system **50** in which a plurality of modules **52** are used to provide a projection-type display. As shown in FIG. **5**, modules **52** may be similar in construction to any of modules **10** with the addition, in some embodiments, of a projection optical system **62** that projects an image of modulator **12** onto screen **54**. Optical system **62** may comprise any suitable arrangement of lenses, mirrors, and/or other optical elements. In some cases an optical system **62** may direct light at an angle to the optical axis of module **52**. For example, an optical system **62** may deflect light from a centrally-located module **52** to illuminate an area **56** in a corner of screen **54**. In some embodiments each module **52** has its own optical system **62**.

In some cases where screen **54** is far enough away from modules **52** it may be unnecessary to provide an optical system **62** on the outer side (i.e. the screen side) of modulator **12** as the light sources of modules **52** may produce light that is well-enough collimated to image the modulator **12** onto screen **54** without focusing on the screen side of modulator **12**.

Each module **52** projects onto a corresponding area **56** of screen **54**. System **50** includes enough modules **52** so that the entire area of screen **54** is covered by areas **56** corresponding to the modules **52**. Typically at least most of modules **52** have corresponding areas **56** that are much smaller than screen **54**. For clarity, FIG. **4** shows only two areas **56**. Every spot on screen **54** preferably lies within two or more areas **56**. Most preferably, every spot on screen **54** lies within 4 or 5 more areas **56**. In currently preferred embodiments of the invention, each point on at least a main viewing area of screen **54** lies within 5 to 15 areas **56**. It is not necessary that there be the same number of overlapping areas **56** at every point on screen **56**.

Modules **52** should be mounted rigidly so that the locations and orientations of the corresponding areas **56** do not move on screen **54**. Modules **52** may be mounted on one or more backplanes **32** as described above, or modules **52** may be mounted in some other manner. For example, modules **52** may be mounted individually or in bundles. Modules **52** may be arranged in one or multiple banks of modules or may be distributed individually. System **50** may include a large number of modules **52**. For example, some embodiments of system **50** include 1000 to 15,000 modules **52**.

Modules **52** may be located in any suitable locations including the ceiling of a theater or other room. Modules **52** may optionally be thermally coupled to air conditioning or other air ducts to help to maintain modules **52** within a desired operating temperature range.

Signals and electrical power may be provided to modules **52** in any suitable manner. A single video and power cable or data bus may extend to all modules **52**. In the alternative, separate power and video cables may connect to different modules **52** or different groups of modules **52**. Modules **52** may receive signals by way of wires, optical fibres, or wireless communication methods. Communication of signals to modules **52** may be simplified because the same data may be provided to all of modules **52** (or, in some embodiments, all modules **52** of each color).

A controller **58** provides image data to modules **52**. Each module **52** emits a pattern of light according to the image data. The image data is, or is based on, data received at an image input **59**. With modules as illustrated in FIG. **5**, the pattern of light is determined by the intensity at which light source **14** is operated as modulated, on a pixel-by-pixel basis by modulator **12**.

It is possible, but not necessary, to carefully align modules **52**. The orientations and locations of the areas **56** corresponding to the different modules **52** may be essentially random as long as every point on the viewing area of screen **54** is covered with an appropriate number of overlapping areas **56**. Areas **56** are not necessarily all the same shape or size. Areas **56** are not necessarily squares, rectangles or other regular shapes. For example, in some embodiments, areas **56** may be trapezoidal or elliptical, partly or entirely as a result of the angles at which the corresponding modules **52** are directed at screen **54**.

Areas **56** are not necessarily the same size. Different modules **52** may have projection optics which cause the modules to cover differently-sized areas **56**. For example, some modules **52** may have wide-angle lenses which cause the corresponding areas **56** to be large, possibly, in some cases, covering a significant fraction of the entire screen **54** or even the entire screen **54**. Other modules **52** may have optics that cause the corresponding areas **56** to be quite small.

Arranging modules **52** so that areas **56** are not arranged in a regular pattern avoids the creation of visible seams in the overall image. It also makes it much easier to install and align modules **52**.

FIG. **5** is a schematic view of a module **52**. Elements of module **52** are labeled using the same reference numerals used for corresponding elements of module **10**. In preferred embodiments, the brightness of light source **14** can be controlled over a reasonable range. For example, light source **14** may be driven by an 8-bit driver that provides 256 brightness levels.

To achieve a bright image on screen **54** it is desirable that modules **52** be optically efficient. One way to make modules **52** optically efficient is to make modulator **12** a monochrome modulator. The color of the light emitted by the module **52** can be determined primarily by the color of light source **14** or, less desirably by a color filter. In embodiments that employ monochrome modules, system **50** may include modules **52** having light sources that emit different colors of light. For example, some modules **52** may have sources of red light, others may have sources of green light and others may have sources of blue light. In such embodiments, it is desirable that areas **56** corresponding to two or more, and preferably three or more modules **52** of each color should overlap at each point in the viewing area of screen **54**. A system **50** may include modules **52** of three or more colors chosen to provide a suitable color gamut for the images to be displayed.

The optical efficiency of a module **52** may be further increased by making modulator **12** have a relatively low resolution. Lower-resolution modulators tend to have higher fill-factors than higher-resolution modulators. This typically results in higher overall optical efficiency. For example, modulators **12** may have a resolution of a few-dozen to a few hundred pixels in each direction. For example, in some embodiments, light modulators **12** have fewer than 500 pixels in at least one direction. In some embodiments, light modulators **12** have fewer than 2^{20} pixels. In one embodiment, modulators **12** have resolutions of 320 by 240 pixels.

Where modulator **12** preferentially passes light of a particular polarization state, light source **14** may be selected and arranged to emit light in the polarization state that is preferentially passed by modulator **12**. For example, where modulator **12** is an LCD that passes light that is linearly polarized in a certain direction, light source **14** may be an LED that emits polarized light and the LED may be aligned so that the polarization of the emitted light is aligned with the polarization direction of the LCD.

In cases where each module **52** generates light of one color, it is possible to operate each module **52** at a reduced refresh rate in comparison to systems that use one modulator to time-multiplex several colors.

System **50** includes a camera **60** located to take images of screen **54**. Camera **60** may be used in various ways. Camera **60** is a high-resolution camera. A primary use for camera **60** is for calibrating system **50**. Since camera **60** is required only for calibration purposes, camera **60** does not need to be present except during calibration of a system **50**. For example, a single camera **60** may be shared among several systems **50**.

In some embodiments, camera **60** may be connected to a system that performs calibration while system **50** is operating. In such embodiments the calibration system may monitor the intensity of light at various combinations of points over time and, from the monitored intensities and the image data, obtain information regarding the calibration of individual modules (e.g. obtain information regarding the brightness provided by one or more modules, or pixels or groups of pixels thereof, in response to brightness values specified by the image data) or the accuracy of the responsibility maps for individual modules (e.g. obtain information defining the area **56** corresponding to each module **54**). The information may be obtained, for example, by performing statistical analysis of the monitored intensities.

FIG. **6** is a flow chart illustrating a method **80** that may be practiced in the initial set up of system **50**. Method **80** may be practiced separately for each color. Method **80** may be performed by a processor in controller **58** operating under the control of software. It is only necessary to perform method **80** once when system **50** is first set up or when it is desired to recalibrate system **50** for some reason.

In block **82** a module **52** is selected. In block **84** a pattern is projected from the selected module. In block **86** the projected pattern is imaged by camera **60**. In block **88**, image processing functions are applied to determine the location and orientation of the area **56** corresponding to the currently-selected module **52**.

Blocks **84**, **86** and **88** may be performed simultaneously for two, or even several modules **10** if the areas **56** corresponding to the two, or several, modules can be distinguished from one another. For example:

- Where camera **60** is a color camera, modules projecting light of different colors may be operated at the same time to project onto corresponding areas **56**. The colors may be used to identify the area **56** corresponding to each of the modules.
- Different modules that are known to project light on different parts of screen **54** may be operated at the same time and the resulting light patterns imaged by camera **60** at the same time. For example, the screen may be divided into quadrants and modules **52** that are known to project into different quadrants may be operated and imaged at the same time.
- Modules **52** may be operated simultaneously to project light patterns that can be readily distinguished from one another. The image obtained by camera **60** may then be processed to correlate areas **56** in the image with the corresponding module **52** by identifying the patterns.
- Some combination of the above, or the like.

In block **90** a decision is made as to whether there are more modules **52** to process. If so, loop **92** is repeated until all of modules **52** have been processed.

In block **94**, method **80** determines which modules **52** contribute to each pixel on the image displayed on screen **54**. In block **96**, for any pixels which are contributed to by two or more modules **52**, responsibility for the pixel is allocated among the modules **52**. The allocation may be, but is not necessarily equal. For example, if a pixel on screen **54** can be illuminated by five different modules **52**, each of those five modules **52** may be given ⅕ responsibility for that pixel. The responsibility may take into account the measured brightness of the image projected by the module **52**. This way the method can automatically compensate for variations in brightness among light sources **14** of different modules **52**.

In block **98**, a map is built for each module **52**. The map identifies pixels of the image on screen **54** for which the module **52** has full or partial responsibility. The responsibility map also specifies a correlation between pixels of the image on screen **54** and pixels of modulator **12** of the module **52**. The responsibility map for each module is stored. The responsibility map may comprise an image at the same resolution as images to be displayed by system **50** on screen **54**. For each module **52**, the responsibility map is "black" (i.e. has values indicating that the module **52** has no responsibility) for pixels of the image outside of the area **56** corresponding to the module **52**. In the responsibility map, pixels of the image inside of the area **56** corresponding to the module **52** have values depending upon the amount of responsibility allocated to the module **52** in block **96**.

For example, consider the case where, for a particular pixel in the image on screen **54**, twelve areas **56** overlap. In this case, each of the 12 modules **52** may be allocated $1/12$ responsibility for the pixel. That pixel in the responsibility maps for the 12 modules **52** could have a value of $1/12$ while that pixel in the responsibility maps for other modules **52** could have a value of 0.

The responsibility maps may be stored in the corresponding modules **52** or in other locations accessible to processors responsible for controlling the operation of modules **52**. In some embodiments, a separate processor is provided for each module **52**. The processor and storage for the responsibility map may be included in the control circuits **24** of the module **52**.

Optionally, the responsibility maps may be modified to provide overall adjustments to the image. For example, the responsibility map may be adjusted to reduce overall brightness from the center of screen **54** to edges of screen **54** or the like.

Providing responsibility maps for each module **52** permits simplified playback of video or other images on system **50**. FIG. **7** illustrates a playback method **100** that may be performed at each module **52**. The same video data may be provided as an input signal to every module **52**. In block **102** the module **52** receives the signal. In each module **52** method **100** is performed for only one color.

In block **104** a frame in the signal is multiplied by the responsibility map. This yields a reduced image much smaller than the full frame. In block **106** a brightness for light source **14** is determined based upon the reduced image. This may be done in any suitable way. For example, block **106** may be performed in the manner described in U.S. Pat. No. 6,891,672 which is hereby incorporated herein by reference.

In block **108** the pattern of light that will be produced by light source **14** on the pixels of modulator **12** is determined. This computation will typically be quite simple as each module **52** typically includes only one light source **14** and the module **52** may be designed so that the light source **14** illuminates modulator **12** at least fairly evenly.

In block **110** the reduced image from block **104** is divided by the light pattern determined in block **108** for each pixel of modulator **12** to obtain driving values for each pixel of modulator **12**. Typically, the arrangement of pixels of modulator **12** will not be precisely aligned with the image to be displayed on screen **54**. Therefore, block **110** typically includes a step of mapping image pixels of the reduced image to be displayed to the pixels of modulator **12** that contribute to those image pixels. In block **112**, light source **14** and modulator **12** are driven with the values determined in blocks **106** and **110** to project a portion of the image onto screen **54**. The images projected by all of modules **52** merge to create the entire projected image.

It can be seen that method **100** can be performed with relatively few operations. Method **100** can be performed for each module **52** with a relatively simple processor. The main operations required to perform method **100** are only:

- a single per-pixel multiply operation at the resolution of the incoming video signal;
- a single per-pixel divide operation at the much lower resolution of modulator **12**.

Since each module **52** displays only one color, the refresh rate of each module **52** can be relatively slow. For example, 24 Hz or so. The refresh rate of modules **52** may be the same as the frame rate of the image signal provided to modules **52**. Optionally, light sources **14** may be flashed on and off a few (e.g. two or three times) per cycle (i.e. per frame in the case where video is being displayed). Flashing the light sources **14** on and off provides a higher flicker frequency.

Power consumption of a system **50** can be reduced through the use of optically efficient modules **52**. For example, consider a system **50** comprising 10,000 modules **52**. If a particular screen requires a maximum illumination of 10,000 Lumens of luminous flux then each module **52** must produce only 1 Lumen. If modulators **12** comprise high-efficiency monochrome LCD panels having optical efficiencies of 40% then light sources **14** would need to produce about 2½ Lumens. A 50 mW LED can produce about 2½ Lumens. Thus such a system **50** would have a power consumption of only 50 mW×10,000=1 kW plus the power required to run any control circuitry. This compares favorably to the 3 kW power consumption of conventional cinema projectors. Power consumption can be minimized by the use of high-efficiency modulators **12**.

It can be appreciated that a system **50** may have at least some of the following advantages:

- The image on screen **54** may be made very large by providing a sufficient number of modules **52**;
- If a module **52** fails it may be replaced without affecting other modules **52**—in the alternative, calibration method **80** can be performed without the defective module **52**, this will result in other modules **52** compensating for the missing module **52**;
- Since method **80** is based upon images of light projected onto screen **54**, the method can compensate automatically for the presence of dirt, damage or other imperfections in screen **54**;
- The effective resolution of images displayed on screen **54** is increased due to the large total number of pixels in system **50**. The effective resolution is increased further by the spatial dither resulting from the fact that each pixel of the projected image is composed of several (e.g. an average of 10 or so) pixels from modules **52**;
- The dynamic range of images that can be displayed on screen **54** is increased;
- Individual modules **52** can be cost effective because modulators **12** can be relatively very small monochrome light modulators;
- The small size of modules **52** and the fact that modules **52** can be distributed in locations such as ceilings, walls and the like provides design flexibility. A theater equipped with a system **50** would not require a separate projection room as is required to contain a traditional cinema projection system.

Various modifications to the displays depicted in FIGS. **4** to **7** are possible. For example:

- In addition to red-, green- and blue-emitting modules **52**, modules **52** of other colors may be provided. Such modules may permit the display of images with a wider color gamut. For example, yellow- and cyan-emitting modules **52** may be provided in a system **50**.
- The system **50** may include different numbers of modules **52** that project light of each of several different colors. The areas **56** corresponding to modules of different colors may be of different sizes.
- Modulator **12** may comprise a reflection-type modulator instead of a transmission-type modulator. For example, modulator **12** may comprise a digital mirror device ("DMD"). Appropriate optical systems may be provided to route light from a light source to a reflection-type modulator and to project light onto screen **54** after it has been modulated by the modulator. Suitable optical systems are routine in the art and are therefore not described in detail herein.
- A system may be made up of two groups of modules **52**. A first group emits light of a first polarization and a second group emits light having a second polarization orthogonal to the first polarization. Such modules may be equipped with polarizing filters. The polarizing filters may be integrated with modulators **12** or may be separate. In the alternative, or in addition, such modules may have light sources **14** that produce polarized light. Such

a system can be used in conjunction with viewing spectacles having orthogonal polarizing filters to provide 3-dimensional images.

In some cases it may be desirable to provide separate source images for different regions of screen **54**. In such cases, each module **52** needs only to receive the source image signal for its region of screen **54**. This reduces the volume of data to be processed at each module **52** and consequently, eases the data processing burden on the data processor handling the module **52**.

The processors associated with modules **52** may perform additional functions such as blur correction. Various suitable blur correction algorithms are known to those skilled in the field of image processing.

A system **50** may be configured as a rear-projection system or a front-projection system. Where system **50** is configured as a rear-projection system it is desirable to place camera **60** on the viewing side of screen **54**.

Partial benefits of the invention may be obtained by providing modules **52** in which only modulator **12** is controlled in response to image data and light source **14** remains operating at a substantially constant output.

Some modules may project light of two or more colors (i.e. it is not mandatory that all modules be monochrome modulators).

Certain implementations of the invention comprise computer processors which execute software instructions which cause the processors to perform a method of the invention. For example, one or more processors in a system **50** may implement the methods of FIGS. **6** or **7** executing software instructions in a program memory accessible to the processors. The invention may also be provided in the form of a program product. The program product may comprise any medium which carries a set of computer-readable signals comprising instructions which, when executed by a data processor, cause the data processor to execute a method of the invention. Program products according to the invention may be in any of a wide variety of forms. The program products may comprise, for example, physical media such as magnetic data storage media including floppy diskettes, hard disk drives, optical data storage media including CD ROMs, DVDs, electronic data storage media including ROMs, PROMs, flash RAM, or the like. In some cases, the program products may comprise transmission-type media such as digital or analog communication links. The computer-readable signals on the program product may optionally be compressed or encrypted. In some embodiments, the program product comprises firmware in a controller **58** of a system **50** or in control circuits **24** associated with a module **52**.

Where a component (e.g. a software module, processor, assembly, device, circuit, etc.) is referred to above, unless otherwise indicated, reference to that component (including a reference to a "means") should be interpreted as including as equivalents of that component any component which performs the function of the described component (i.e., that is functionally equivalent), including components which are not structurally equivalent to the disclosed structure which performs the function in the illustrated exemplary embodiments of the invention.

As will be apparent to those skilled in the art in the light of the foregoing disclosure, many alterations and modifications are possible in the practice of this invention without departing from the spirit or scope thereof. For example:

In systems having an overall structure similar to that of FIG. **4**, color may be provided in any of various different ways. These include providing monochrome modules of at least two and, in most cases three or more different colors or providing modules that each project a color image. Where modules each project a color image, the color image may be obtained in various ways including: providing a color modulator in each module or providing a monochrome modulator operating in a field sequential mode wherein a color of light incident on the modulator is changed for each of a series of fields. The color of light incident on the modulator may be varied by interposing different filters in the light path or by turning on light sources of different colors. For example, each module could include red, green and blue LEDs driven in a field-sequential mode to illuminate a monochrome LCD light modulator. The LEDs may be operated cyclically to issue R, G and B light at a relatively high frequency. The LCD may be operated in synchronization with the cycling of the light sources to present images to be displayed in red, green and blue respectively.

Accordingly, the scope of the invention is to be construed in accordance with the substance defined by the following claims.

What is claimed is:

1. A display comprising:

a plurality of modules, each of the plurality of modules comprising a light source and a spatial light modulator disposed to modulate light emitted by the light source in response to image data; and,

a screen illuminated by the plurality of modules;

wherein each of the modules is capable of illuminating a corresponding area of the screen and the areas of the screen illuminated by different ones of the modules overlap with one another; and

wherein each of the modules comprises a control circuit that is connected to receive a data signal carrying the image data and is configured to generate a driving signal for the light modulator based upon the image data and is associated with a computer-accessible responsibility map, the responsibility map comprising an image at a resolution that is the same as a resolution of an image to be displayed by the display on the screen, the responsibility map identifying those pixels of the image data for which the module is not responsible and those pixels of the image data for which the module has full or partial responsibility and, for each of those pixels for which the module has partial responsibility, identifying a fractional amount of responsibility of the module for the pixel, the responsibility map further specifying a correlation between pixels of the image to be displayed on the screen and pixels of the spatial light modulator of the module;

wherein the control circuits in a plurality of different ones of the modules are connected to receive the same data signal and the control circuit in each of the plurality of different ones of the modules is configured to, using the responsibility map: extract a portion of the image data relevant to the module; map pixels of the extracted portion of the image data to corresponding pixels of the spatial light modulator; and generate the driving signal based upon the extracted portion of the image data and the corresponding amount of responsibility of the module for the pixel; and

wherein for each module, intensities of light from the pixels of the light modulator of the module corresponding to pixels of the image data for which the module has partial responsibility, are controllable by the control circuit based on: the fractional amount of responsibility allocated to the module for the pixel by the responsibility map; and the image data corresponding to the corresponding pixel of the image data such that the intensities of light from the pixels of the light modulator of the module are adjusted in proportion to the amount of responsibility of the module for the pixel according to the responsibility map when the amount of responsibility allocated to the module is greater than 0% and less than 100%.

2. A display according to claim **1** wherein the light source of each of the plurality of modules comprises one or more light-emitting diodes.

3. A display according to claim **1** wherein each of the plurality of modules comprises a first driving circuit connected to control an intensity of light emitted by the light source according to a first control signal and a second driving circuit connected to control an amount of light passed by the light modulator according to a second control signal.

4. A display according to claim **3** wherein in each of the modules the control circuit is configured to generate the first and second control signals in response to the image data.

5. A display according to claim **1** wherein each of the plurality of modules is detachably affixed to a support structure.

6. A display according to claim **5** wherein the support structure comprises a plurality of sections that are detachably affixed to one another.

7. A display according to claim **6** wherein the sections comprise strips, each of the strips extending across the display, each of the strips supporting a plurality of the modules.

8. A display according to claim **6** wherein the sections comprise tiles, each of the tiles supporting a plurality of the modules.

9. A display according to claim **5** wherein each of the modules comprises a first power connector, and the first power connector connects to a second power connector corresponding to the module and mounted to the support structure when the module is affixed to the support structure.

10. A display according to claim **5** wherein each of the modules comprises a thermally-conductive member in thermal contact with one or more heat-generating components of the module and the thermally-conductive member is also in thermal contact with a heat sink in the support structure.

11. A display according to claim **10** wherein the thermally-conductive member is integrated with the first connector.

12. A display according to claim **1** wherein each of the plurality of modules comprises a light sensor located to collect light emitted by the light source and to generate a signal indicative of an intensity of the emitted light.

13. A display according to claim **12** wherein the light sensor in each of the plurality of modules comprises an end of an optical fiber disposed within the module and the optical fibers carry the emitted light to a common light transducer that generates an electrical signal indicative of the intensity of the light.

14. A display according to claim **13** wherein the optical fibers are anchored to a support structure of the display.

15. A display according to claim **1** wherein each of the plurality of modules comprises light sources of a plurality of different colors.

16. A display according to claim **1** wherein the light source of each of the plurality of modules is one of a plurality of different colors.

17. A display according to claim **1** wherein, in each of the plurality of modules, the light source emits polarized light, the modulator preferentially passes light that is polarized along a polarization axis, and the light emitted by the light source is polarized substantially along the polarization axis.

18. A display according to claim **1** wherein each of the plurality of modules comprises a housing that is opaque to the light emitted by the light source and the housing extends around the light source so as to block the exit of light from the module except through the light modulator.

19. A display according to claim **1** wherein, in each of the plurality of modules, the light modulator has a resolution of less than 500 pixels in at least one direction.

20. A display according to claim **1** wherein, in each of the plurality of modules, the light modulator has fewer than 2^{20} controllable pixels.

21. A display according to claim **1** wherein, for each point in a viewing area of the screen, at least five of the modules are operable to illuminate corresponding areas of the screen that include the point.

22. A display according to claim **21** wherein, for a plurality of different points on the screen, a different number of modules of the display have corresponding areas that include the point.

23. A display according to claim **22** wherein the screen includes at least some points for which the number of modules of the display that have corresponding areas that include the point exceeds nine and the screen includes some other points for which the number of modules of the display that have corresponding areas that include the point is less than seven.

24. A display according to claim **1** wherein the plurality of modules are arranged at different distances from the screen.

25. A display according to claim **1** wherein at least some of the plurality of modules are mounted at locations that are higher than a top edge of the screen.

26. A display according to claim **25** wherein at least some of the plurality of modules are mounted to a ceiling of a building in which the screen is located.

27. A display according to claim **26** wherein at least some of the plurality of modules comprise a heat-conducting member in thermal contact with one or more heat-generating components of the module wherein the heat-conducting member extends into an air conditioning duct in the ceiling of the building.

28. A display according to claim **1** comprising a digital camera located to image the screen and a control processor configured to perform a calibration routine for building the responsibility maps, the calibration routine comprising:

operating each of the modules to display on the screen a pattern indicative of the location of the corresponding area of the screen for the module;

acquiring an image of the displayed image with the camera; and,

generating the responsibility map by processing the acquired image.

29. A display according to claim **1** wherein the screen is a front projection screen and the modules are located on a viewing side of the screen.

30. A display according to claim **1** wherein the screen is a rear projection screen and the modules are located on a side of the screen opposite to a viewing side of the screen.

31. A display according to claim **1** wherein the plurality of modules include light sources that emit light of at least two different colors.

32. A display according to claim **1** wherein the light modulator of each of the plurality of modules is a monochrome light modulator.

33. A display according to claim **1** wherein one group of the plurality of modules emits light that is polarized in a first direction and another group of the plurality of modules emits light that is polarized in a second direction, wherein the first and second directions are substantially perpendicular to one another.

34. A display according to claim **1** wherein the modules include a first group of modules emitting light of a first color and a second group of modules emitting light of a second color different from the first color.

35. A display according to claim **1** wherein each of the modules illuminates an area on the screen and the screen comprises a plurality of Fresnel lenses with one of the Fresnel lenses in the area illuminated by each of the modules.

36. A display according to claim **35** wherein the screen comprises scattering centers that scatter light toward a viewing location.

37. A display according to claim **36** wherein the scattering centers scatter radiation evenly into elliptical cones.

38. A display according to claim **1** wherein the screen is substantially planar.

39. A display according to claim **1** wherein the screen is curved.

40. A display according to claim **1** wherein the areas of the screen illuminated by adjacent ones of the plurality of modules overlap with one another along strips that are narrow relative to the areas of the screen.

41. A display according to claim **40** wherein in each of the modules the control circuit comprises a processor configured to set drive levels for the pixels of the light modulator that correspond to points within the strips so as cause the sum of the illumination received from all contributing modules at the points to have desired illumination levels.

42. A display according to claim **1** wherein, for those pixels for which two or more of the modules are responsible, responsibility is allocated equally among the modules.

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